

## Test Stand Status

Sebastian Vazquez-Torres  
Ron Belmont  
Jamie Nagle

University of Colorado, Boulder

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Some data about polystyrene (scintillator base material)

|  |                              |
|--|------------------------------|
| $Z/A$                                    | $0.53768 \text{ mol g}^{-1}$ |
| Density $\rho$                           | $1.060 \text{ g cm}^{-3}$    |
| Nuclear interaction length $\lambda_I$   | 77.1 cm                      |
| Radiation length $X_0$                   | 41.31 cm                     |
| Mean excitation energy $I$               | 68.7 eV                      |
| Minimum ionization energy $dE/dx _{min}$ | 2.025 MeV/cm                 |

What about the Bethe formula?

$$-\left\langle \frac{dE}{dx} \right\rangle = \rho K \frac{Z}{A} \frac{1}{\beta^2} \left[ \frac{1}{2} \ln \frac{2m_e c^2 \beta^2 \gamma^2 T_{max}}{I^2} - \beta^2 - \frac{\delta(\beta\gamma)}{2} \right]$$

- $K = 4\pi N_A r_e^2 m_e c^2 = 0.307075 \text{ MeV mol}^{-1} \text{ cm}^2$
- $T_{max} = 2m_e c^2 \beta^2 \gamma^2 / [1 + 2\gamma m_e / M + (m_e / M)^2]$  is the highest kinetic energy that can be imparted to a free electron in a single collision by a particle with mass  $M$
- The  $\delta(\beta\gamma)$  can be calculated based on Sternheimer et al, Phys. Rev. B 26, 6067 (1982)—note that in their convention the correction doesn't have the factor 1/2  
 $X = \log_{10} \beta\gamma$   
 $X < X_0 \rightarrow \delta(X) = 0$   
 $X_0 < X < X_1 \rightarrow \delta(X) = 4.6052X + a(X_1 - X)^m + C$   
 $X_1 < X \rightarrow \delta(X) = 4.6052X + C$   
 where  $X_0$ ,  $X_1$ ,  $a$ ,  $m$ , and  $C$  are material-specific constants
- Minimum ionizing energy for muon is 318 MeV, using this we obtain  $\langle dE/dx \rangle = 2.036 \text{ MeV/cm}$ , which is quite close to the 2.025 MeV/cm from the data table

Generally we consider the distribution of energies to be a Landau  
The Landau distribution is defined by

$$f(\lambda) = \frac{1}{2\pi i} \int_{c-i\infty}^{c+i\infty} e^{s \ln s + \lambda s} ds$$

due to the long tail, the moments are undefined.

However, as derived in J. E. Moyal, Phil. Mag. 46 (1955) 263, the Landau distribution can be well approximated by

$$f(\lambda) = \frac{1}{\sqrt{2\pi}} e^{-\lambda + e^{-\lambda}}$$

which later became known as the Gumbel distribution.

The moments of the Gumbel distribution are defined: for  $\lambda = (x - \mu)/\sigma$ , the mode (MPV) is  $\mu$  and the mean is  $\mu + \gamma_E \sigma$  (where  $\gamma_E \approx 0.577216$  is the Euler-Mascheroni constant)

For energy loss in a material, we can write the energy loss distribution as

$$\Delta E = \frac{1}{\sqrt{2\pi}} e^{-\lambda + e^{-\lambda}}$$

where the independent variable  $\lambda$  is

$$\lambda = \frac{\Delta E - [\Delta E]_{MPV}}{\xi}$$

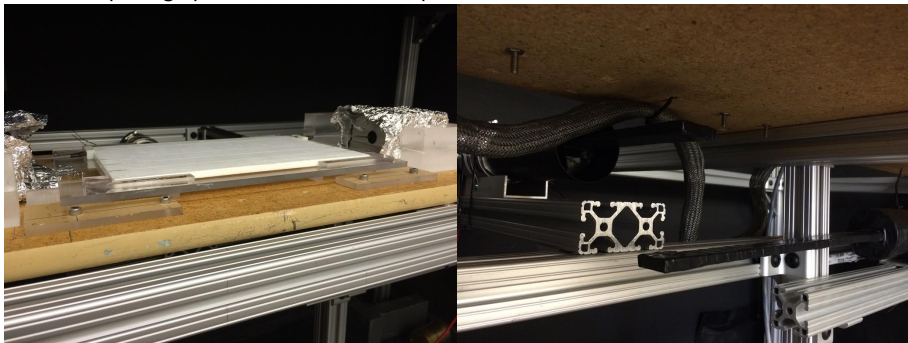
the width parameter  $\xi$  is

$$\xi = \frac{K}{2} \frac{Z}{A} \frac{1}{\beta^2} \rho \Delta x$$

and the most probable value of the energy loss can be determined by a modified Bethe formula

$$[\Delta E]_{MPV} = \xi \left[ \ln \frac{2m_e c^2 \beta^2 \gamma^2 \xi}{I^2} - \beta^2 + 1 - \gamma_E \right]$$

Some photographs of the cosmics set up

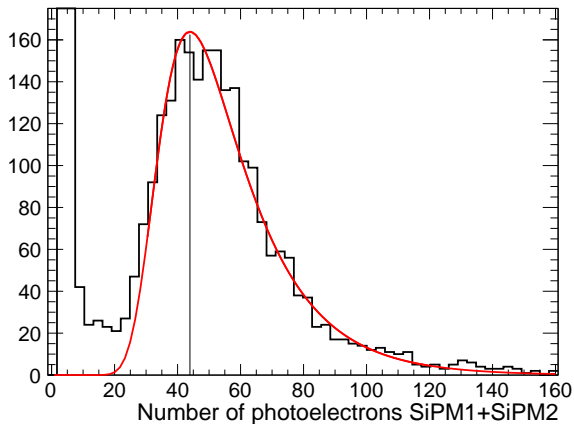


We have both phototubes under the table so that source/LED scans can be run without total deconstruction

We have the upper tube as close to the panel as possible to minimize the fraction of particles that trigger both tubes but miss the panel

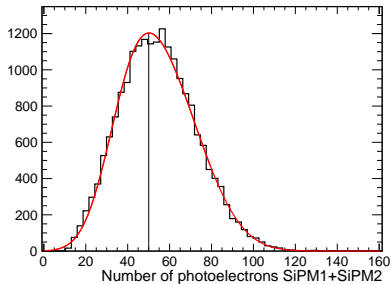
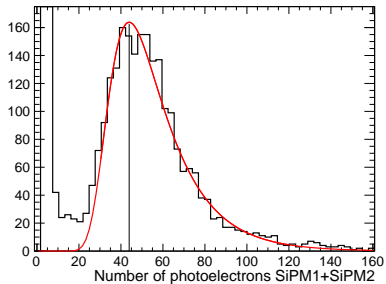
A little about the geometry...

- The two phototubes are separated by about 3.25", each having 0.25" thickness, and each has a 1"  $\times$  1" scintillator
- The maximum angle off-normal is  $\theta_{max} = \tan^{-1}(3.75/\sqrt{2}) \approx 0.361 \approx 20.7^\circ$
- The pathlength  $L$  is related to the thickness  $\Delta x$  by  $L = \Delta x \sec \theta$ , meaning  $L_{max} = \Delta x \sec \theta_{max} \approx 1.07 \Delta x$
- Panel thickness 0.300" = 0.762 cm
- For the sake of simplicity, we'll ignore the 7% possible deviation in pathlength... for MIP we get  $[\Delta E]_{MPV} = 1.37$  MeV and  $\xi = 0.0750$  MeV

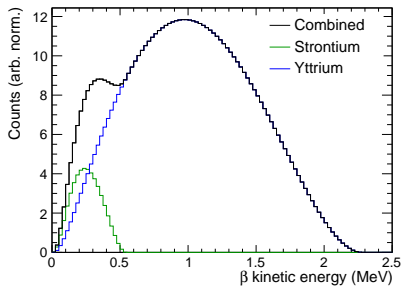
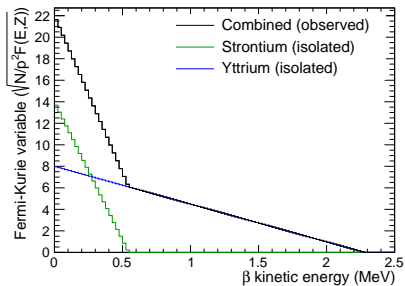


$[\Delta E]_{MPV} = 43.9 \pm 0.5$  photoelectrons and  $\xi = 9.3 \pm 0.2$  photoelectrons

What can we learn by comparing the distribution from the Strontium-90 source to the cosmics?

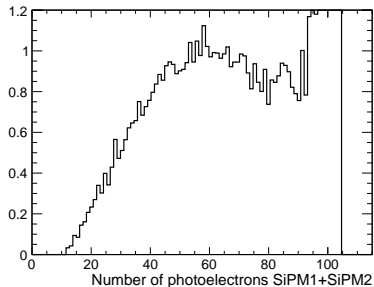
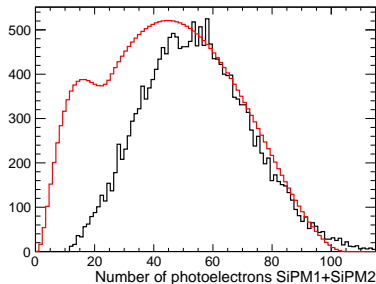


What does the Strontium source spectrum look like?



Data from W. E. Meyerhof, Phys. Rev. 74 (1948) 263

## Overlay of the source spectrum with measured distribution



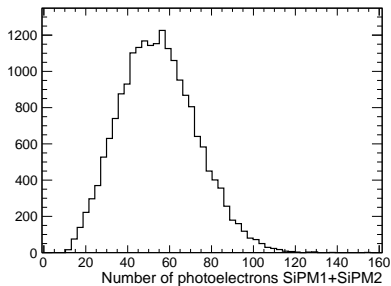
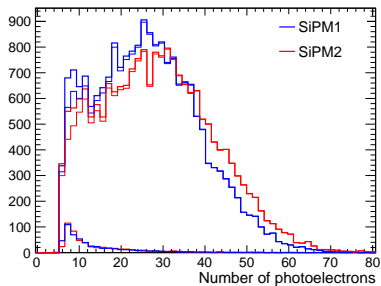
There seems to be some inefficiency at low energies, and the ratio resembles a turn-on curve—further investigation is needed

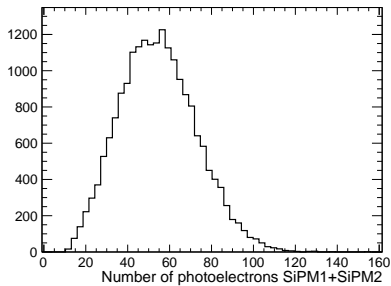
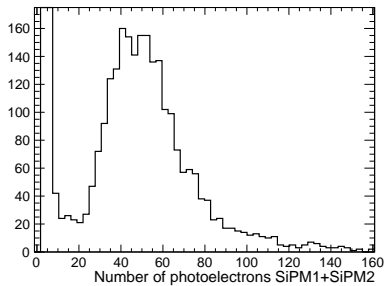
Reminder: we use the SiPMs to self-trigger on the source, so there's an inherent low energy cut-off

- Cosmics have been measured with a mean of 43.9 pe and a width of 9.3 pe
- We are prepared and able to do cosmics measurements as soon as we get the full size tiles from BNL
- We are seeking input to going further using cosmics to characterize the energy deposited in the tile
- We can also do an LED scan as soon as we receive them—we plan to do LED scans with the tile inverted, i.e. facing away from the LED so that light going directly into the fiber isn't an issue
- It may also be possible to use the Strontium-90 source to calibrate the energy, though further investigation is needed
- The sampling of the light in the fiber relative to the total light produced may be an important additional consideration

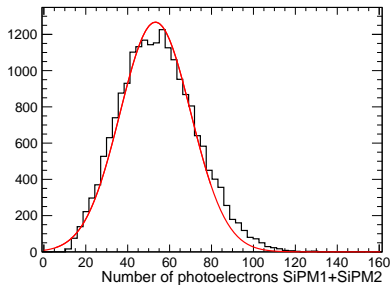
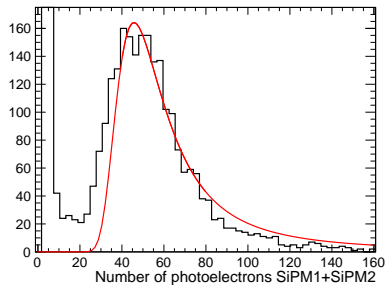
Extra material

Source distribution, comparison between each SiPM and the sum

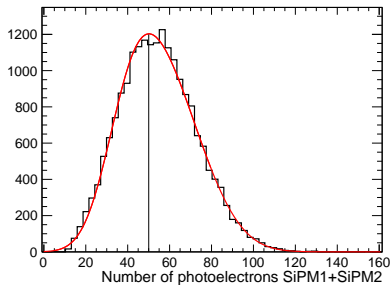
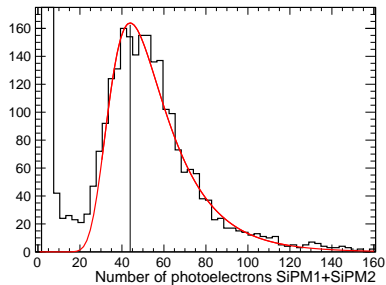




Raw distributions



Built-in Landau for cosmics, Built-in Gaussian for source



Gumbel for cosmics, modified Gaussian for source